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Enhancement of a Global Soil Pedon Database

The goal of my summer internship was to finish enhancing and revising the ORNL-UCB Worldwide Organic Soil Carbon and Nitrogen database, and use the data to estimate the amount of organic carbon and nitrogen stored in soils globally. My work involved completing the enhancements of the soil database and combining the information with the FAO-Unesco Soil Map of the World. The database contains information about carbon, nitrogen, and base cations in over 4100 soil profiles along with information on data handling methods and environmental information. The enhanced database will include over 100 additional soil profiles, but most importantly contain soil taxonomic information that allows integration with soil maps, in particular the FAO soil map. The data will be available to the public electronically through an FTP site. I computed mean C and N according to depth. Combining these means with global spatial distributions of soil units I calculated global totals of C and N according to soil unit and total areas of soil units according to continent. We estimated that 1,622.18 Pg C and 107,118.50 Tg N are stored in the soil globally. This provides basic information that can be used in determining the role of soil in sequestration or release of CO_2 with the atmosphere.

Introduction

The ORNL-UCB Soil Profile Database consists of measurements of soil organic matter element amounts from samples taken from soils under natural vegetation. An attempt was made to gather a sufficient number of soil profiles to represent the carbon content of the world's soils. Many factors influence the properties of soils. The most important include climate, vegetation, parent material, and topographic position. Soil taxonomic systems attempt to organize the observed variation of soils into relatively uniform classes that account for these simultaneous influences as expressed in soil properties (Post, 1999).

When the original ORNL-UCB Soil Profile Database was published, there was no worldwide consensus among scientists on how to classify soils. The United States Department of Agriculture had recently introduced the 7^{th} Approximation taxonomic system, and the majority of other countries were beginning to use the newly published FAO-Unesco (Food and Agriculture Organization-United Nations Educational & Scientific Cultural Organization) taxonomic system. A need to classify soils worldwide in order to characterize the properties of each soil type and compute land area was critical for the success of a database everyone could utilize. It would be most appropriate to compute land areas based on soil type, and thereby representing soil forming processes and soil properties in the most uniform way. However, other methods were used. These included estimates of land areas based on climate classification, ecosystem type, and land areas computed by latitude belts.

The Holdridge Life-Zone Classification system (Holdridge, 1947) which uses climate to classify soil types was the system used to designate and then compute total land areas. This method produced estimates of global soil carbon content at 1,308.6 Pg and global soil nitrogen content at 96,781.4 Tg. The other method used was the combination of north & south latitudes into one-degree latitudinal bands to compute land areas. This method produced higher values than the Hodridge system. Global soil carbon content was estimated at 1,728.0 Pg and global soil nitrogen content at 117,000 Tg (Zinke, et al. 1985).

Methods

The revision of the ORNL-UCB soil pedon database not only allows the enhancement of the database itself, but the chance to represent the global soil carbon and nitrogen content by FAO soil type. A FOXPRO database management file was constructed and individual profile reports containing all coded information for each profile were printed. This database was then converted to Microsoft Excel spreadsheets to be revised.

My first goal was to assign FAO soil types to any profiles in the database that had coordinates pointing to areas of water, salt flats, sand dunes, or no data. We did this by referring to the FAO-Unesco Soil Maps of the World. After revising, I categorized the 4, 276 soil profiles by continent and by soil type. Taking the amount of carbon and nitrogen in each soil type, I was able to compute the worldwide mean organic carbon and nitrogen contents, and the carbon to nitrogen ratio for 20cm depth and 100cm depth for the 106 FAO-Unesco classified soils.

I took the FAO-Unesco Digital Soil Map of the World and totaled the land areas that corresponded to the particular soil type. I was then able to estimate the global totals of carbon and nitrogen content in the soil. We computed a global soil carbon content of 1,622.18 Pg and a global soil nitrogen content of 107,118.50 Tg.

The benefits of using soil classification to compute mean carbon and nitrogen, instead of the Holdridge system or the one degree latitudinal bands, are that all soil forming factors, which are climate, topography, time, parent material and soil organisms, are accounted for. In the other two methods of computing land area, only a few of the soil forming factors were looked at.

The values of mean organic carbon, mean nitrogen, and carbon to nitrogen ratios for 100cm depth were joined with the FAO-Unesco Digital Soil Map of the World database using ArcView, a Geographic Information Systems program. The results of this join are shown in the four maps displayed. North and Central America is enlarged to show the complexity of soil contents. The worldwide organic carbon content map was made to give an idea of the carbon content globally.

Table 1. Summary by FAO-Unesco Order to 20 cm depth.

FAO NAME	C ($kg\ m^{-2}$)	Global (Pg C)	N ($g\ m^{-2}$)	Global (Tg N)	C/N ($g\ g^{-1}$)
A Acrisol	6.79	56.79	373.62	3124.77	18.17
B Cambisol	9.58	86.14	549.82	4941.5	17.43

C Chernozem	11.6	23.34	1114.1	2243.67	10.4
D Podzoluvisol	7.34	17.97	615.46	1506.89	11.92
E Rendzina	11	5.04	1099	502.67	10.03
F Ferralsol	4.95	50.74	401.19	4114.53	12.33
G Gleysol	7.84	43.14	519.92	2860.78	15.08
H Phaeozem	6.92	10.29	412.93	613.627	16.77
I Lithosol	12.6	278.8	850.85	18892.9	14.76
J Fluvisol	6.77	21.11	594.69	1853.96	11.39
K Kastanozem	5.26	24.18	422.93	1942.67	12.45
L Luvisol	6.48	59.1	429.27	3913.02	15.1
M Greyzem	10.8	3.25	908.48	272.44	11.91
N Nitosol	7.27	15.16	519.63	1083.88	13.99
O Histosol	22.1	52.94	632.92	1518.93	34.86
P Podzol	9.22	42.48	576.1	2654.43	16
Q Arenosol	2.64	8.63	254.95	834.68	10.34
R Regosol	4.21	26.72	281.83	1787.27	14.95
S Solonetz	8.71	9.29	746.33	796.05	11.67
T Andosol	16.7	15.72	961.51	906.34	17.34
V Vertisol	4.36	13.46	399.05	1232.87	10.92
W Planosol	7.23	6.69	618.42	572.28	11.69
X Xerosol	5.44	23.72	342.34	1492.34	15.9
Y Yermosol	4.56	35.26	253.05	1955.3	18.04
Z Solonchak	6.35	1.58	416.37	103.84	15.26
ALL SOILS	8.27	931.54	571.79	61721.64	14.75

Table 1 is a summation of the global carbon and nitrogen soil content to 20cm depth using the FAO-Unesco Taxonomic Order for classification. The carbon (kg/m^2) and nitrogen (g/m^2) soil content data was taken from the ORNL-UCB soil profile database. We used soil order areas from the FAO-Unesco Digital Soil Map of the World to calculate the global soil carbon and nitrogen totals. We estimated that there is currently a total of 931.54 Pg C and 61,721.64 Tg C stored in soils around the world in the first 20cm.The carbon to nitrogen ratio was calculated at 14.75 (g/g).

Table 2. Summary by FAO-Unesco Order to 100 cm depth.

FAO NAME	C (kg m^{-2})	Global (Pg C)	N (g m^{-2})	Global (Tg N)	C/N (g g^{-1})
A Acrisol	12.38	103.56	717.44	6000.35	17.26
B Cambisol	18.7	168.08	1040.8	9354.38	17.97
C Chernozem	16.38	32.99	1359.62	2738.12	12.05

D Podzoluvisol	10.66	26.1	787.47	1928.03	13.54
E Rendzina	16.95	7.75	243.28	111.27	69.68
F Ferralsol	10.53	107.97	1006.61	10323.5	10.46
G Gleysol	14.3	78.7	998.48	5493.92	14.32
H Phaeozem	10.83	16.09	679.77	1010.17	15.93
I Lithosol	18.88	419.32	1254.98	27866.3	15.05
J Fluvisol	11.44	35.66	890.45	2775.99	12.85
K Kastanozem	9.7	44.56	861.34	3956.45	11.26
L Luvisol	10.86	98.96	761.25	6939.23	14.26
M Greyzem	15.65	4.69	1107.96	332.26	14.12
N Nitosol	13.03	27.17	890.75	1857.96	14.63
O Histosol	57.97	139.11	1713.86	4113.06	33.82
P Podzol	15.34	70.67	960.51	4425.65	15.97
Q Arenosol	6.36	20.82	52.14	1840.39	11.31
R Regosol	6.21	39.39	432.96	2745.72	14.35
S Solonetz	12.84	13.7	839.3	895.21	15.3
T Andosol	27.22	25.66	1511.88	1425.13	18.01
V Vertisol	8.7	26.88	890.47	2751.16	9.77
W Planosol	15.53	14.37	1253.89	1160.32	12.38
X Xerosol	9.21	40.13	905.77	3948.41	10.16
Y Yermosol	7.41	57.22	377.91	2920.13	19.6
Z Solonchak	10.53	2.63	823.54	205.385	12.79
ALL SOILS	14.70	1622.18	894.50	107118.50	17.07

Table 2 is a summation of the global carbon and nitrogen soil content to a 100cm depth using the FAO-Unesco Taxonomic Order. The same methods were used in calculating the global totals of carbon and nitrogen. We estimated that there is a total of 1,622.18 Pg C and 107,118.50 Tg N stored in the soils around the world in the first 100cm. The carbon to nitrogen ratio has been calculated at 17.07 (g/g).

Results

N.H. Batjes conducted a similar study in 1996 creating his own soil profile database, the World Inventory of Soil Emissions (WISE), and estimated global carbon and nitrogen totals (Batjes, 1996). We used the same methods to calculate land area as Batjes, and the results are comparable. Batjes estimated that the global soil carbon content is between 1,462 Pg and 1,548 Pg. Batjes also estimated the global soil nitrogen content to be between 133 Pg (133,000 Tg) and 144 Pg (144,000 Tg). The reasons for the differences in totals are in the databases themselves. Batjes had 4353 soil profiles, yet they are not all of the same profiles that we had in the ORNL-UCB database. The majority of profiles in his database are from Africa, while the majority of soil profiles in the ORNL-UCB database are from North America.

Conclusions

We estimated that 1,622.18 Pg C and 107,118.50 Tg N are stored in the soil globally. This provides basic information that can be used in determining the role of soil in sequestration or release of CO_2 with the atmosphere.

An idea for future estimations of organic soil carbon and nitrogen contents is a merge of the revised ORNL-UCB database, the WISE database, and other databases that are available. This would create a uniform representation of the distribution of soils on Earth, enabling estimations of global organic carbon and nitrogen contents to be more accurate.

References:

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 47:151-163.

FAO 1990. FAO-Unesco Soil Map of the World: Revised Legend. World Resources Report 60. Food and Agriculture Organization of the United Nations, Rome.

FAO 1992. The Digitized Soil Map of the World: Release 1.1. Food and Agriculture Organization of the United Nations, Rome.

Holdridge, L. R. 1947. Determination of world plant formations from simple climatic data. Science 105:367--368.

Post W. M., Emanuel W. R., Zinke P. J., Stangenberger A. G. 1982. Soil carbon pools and world life zones. Nature 298:156--159

Post W. M., Pastor J., Zinke P. J., Stangenberger A. G.1985. Global patterns of soil nitrogen storage. Nature 317:613--616

Zinke P. J., Stangenberger A. G., Post W. M., Emanuel, W. R., Olson J. S.1984. Worldwide Organic Soil Carbon and Nitrogen Data. Oak Ridge National Laboratory, Oak Ridge, Tennessee (ORNL/TM--8857)

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